THE IMPORTANCE OF EDGE FOR NATANT MACROFAUNA IN A CREATED SALT MARSH

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Abstract: The relationship between marsh edge and animal use was examined in a planted *Spartina alterniflora* marsh located in the Galveston Bay system of Texas. A completely randomized block experimental design was used with each of four blocks containing a control and experimental sector. Marsh edge was increased through the construction of channels in experimental sectors. Channel construction had no detectable effect on marsh surface elevation. Effects of these simulated tidal creeks on habitat use were examined by sampling nekton at high tide with drop enclosures both on the marsh surface and within the channels. Crustaceans dominated the nekton, and use of the marsh surface in experimental sectors was significantly higher than in controls; densities of brown shrimp *Penaeus aztecus,* white shrimp *P. setiferus,* and daggerblade grass shrimp *Palaemonetes pugio* were 4.6 to 13 times higher near the channels. Polychaete densities in marsh sediments were also significantly higher near channels, and densities of decapod predators were positively correlated with densities of these infaunal prey. Thus, channel effects on natant decapods may have been related to the distribution of prey organisms. However, increased densities of natant fauna along the channel edge may simply reflect a requirement for departure from the marsh surface at low tide. Marsh-surface densities of small bait fishes, bay anchovy *Anchoa mitchilli* and the inland silverside *Menidia beryllina,* also increased near channels, but highest densities of these fishes were in the creeks themselves. The abundance and distribution of juvenile blue crabs *Callinectes sapidus* and gulf marsh fiddler crabs *Uca longisignalis* were not affected by the addition of experimental channels. Overall, the study results indicate that habitat value of created salt marshes can be enhanced by incorporating tidal creeks into the marsh design.

Key Words: edge, *Spartina,* salt marsh, restoration, transplant, fish, shrimp, crustaceans, habitat complexity, hydroperiod

INTRODUCTION

Many coastal salt marshes in the northern Gulf of Mexico have a large amount of edge (marsh to open water interface), with islands of vegetation interspersed among small creeks, channels, and ponds (Zimmerman et al. 1984, Wells and Coleman 1987, Browder et al. 1989). This reticulated pattern is apparently caused by the cyclic processes of marsh building in a deltaic environment followed by marsh loss due to submergence and eventual conversion to open water (DeLaune et al. 1983, Sasser et al. 1986, Wells 1987, Wells and Coleman 1987, Reed 1989, Reed and Cahoon 1992). Transient fishery species and other estuarine organisms in this region directly exploit intertidal marsh surfaces (Zimmerman and Minello 1984, Thomas et al. 1990, Rozas 1992, Rozas and Reed 1993, Peterson and Tur-

ner 1994), and there is some evidence that vegetation along the marsh edge (marsh-edge habitat) is used to a greater extent than inner marsh habitat (Minello et al. 1991, Baltz et al. 1993, Peterson and Turner 1994). Thus, the amount of edge in a salt marsh may regulate habitat use and affect the value of the marsh for these organisms.

In contrast to the natural marshes of the region, salt marshes created on dredged material in the northern Gulf usually have a low edge:area ratio. In typical marsh construction projects, fine-grained sediment is pumped hydraulically through a large pipe and allowed to accumulate until it becomes subaerial. Marsh substrata built with this fluid material have shallow slopes and little topographic variability. Planted *Spartina alterniflora* Loisel readily vegetates these areas if shoreline energy is low, but the lack of topographic variability
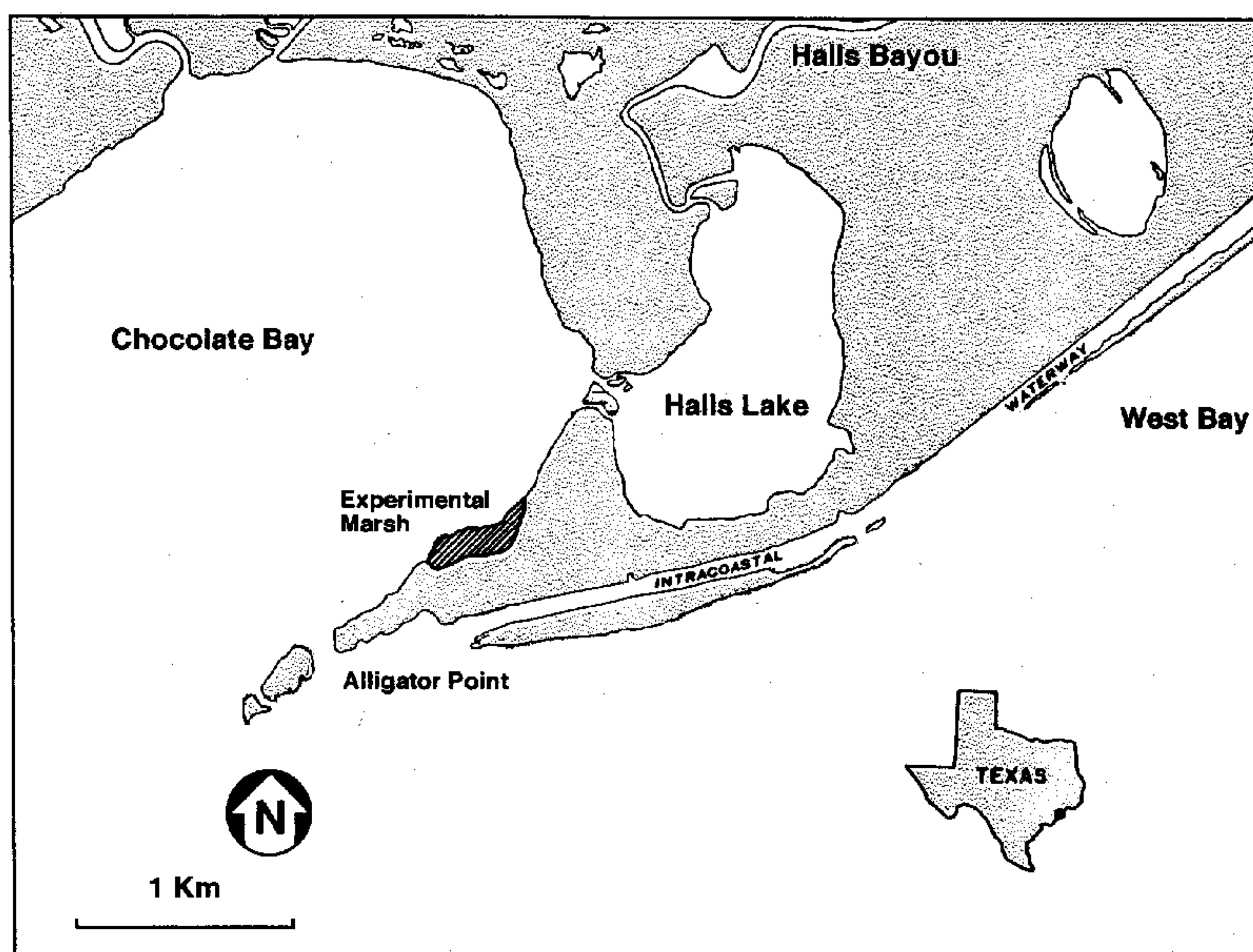
Figure 1. Location of the experimental transplanted *Spartina alterniflora* marsh in the Galveston Bay system of Texas.

results in a solid stand of marsh with few creeks and minimal marsh edge.

The purpose of our study was to examine the effect of edge on animal use within a planted *S. alterniflora* marsh. The study area initially had no channels and minimal marsh edge; edge was increased by constructing experimental channels. The edge effect was assessed by measuring densities of fishes, decapod crustaceans, and benthic infauna in control areas without channels, on the marsh surface near the channels, and within the channels themselves.

METHODS

Description of the Study Area

The Alligator Point salt marsh is located in the Galveston Bay system of Texas (Figure 1). This 8-hectare marsh was created in June 1983 by planting *S. alterniflora* onto dredged material that was deposited along the shoreline of Chocolate Bay. The resulting marsh has a frontage of approximately 600 m on the bay, is 100 to 140 m wide, has a soft silty sediment, and has minimal edge (Figure 2). The topography of the marsh is relatively even with a shallow slope (0.5%) towards the open bay, and there is no berm near the open-water edge. The marsh is mostly a monotypic stand of *S. alterniflora*.

Construction of Channels

An area of the marsh from the bay shoreline to approximately 80 m inland was divided into four blocks, each with 100 m of bay shoreline. Blocks were then divided into two sectors of equal area, each with 50 m of shoreline. In each block, one sector was randomly selected as experimental for the construction of a channel; the other sector was designated as a control. Four channels were constructed in December 1986 using a dragline mounted on a marsh buggy with two low ground-pressure tracks. In each experimental sector, the buggy was driven twice down to the water's edge from the upland portion of the marsh. As the buggy was backed away from the open water, channels were excavated where the buggy tracks had compressed the marsh surface. This procedure minimized impact on the remaining marsh surface. Each retreat from the bay shoreline resulted in two parallel channels (each 1.5–2 m wide and 0.6–0.9 m deep) separated by a 2.1-m wide strip of vegetation. When the first set of channels in an experimental sector extended 60 m into the marsh, the dragline was turned and again driven to the bay shoreline to construct the second set of channels 15–18 m away from the first set. The channels were then connected at their inland ends to form a U-shaped double channel (Figure 3). To facilitate water exchange, the parallel channels were interconnected at five lo-

Figure 2.   Aerial view of the experimental channels. The photograph was taken about 1 month after channel construction; the light colored areas surrounding channels are nonvegetated piles of sediment removed to create channels.

cations. Care was taken in the removal of sediment so that no berm was created along the channel edges. The sediment was placed as far from the channels as possible (about 8–10 m) in six piles along the outside of the "U" (Figures 2 and 3).

In reporting our study results, we have used the term "outer marsh" to denote all habitats (vegetated and nonvegetated) nearest the open water of Chocolate Bay; nonvegetated bottom just offshore of the marsh was considered an outer marsh habitat (Figure 3). The term "inner marsh" is used to identify habitats away (> 30 m) from the open bay, including nonvegetated bottom within experimental channels.

Sampling

Animal use of the marsh surface was measured during the spring of 1987 (on May 28, ca. 5 months following channel creation) and during the spring (May 31–June 1) and fall (September 20–22) of 1988. The spring and fall seasons are periods when young fishes and crustaceans are abundant and high water levels make salt marshes in the northern Gulf of Mexico most accessible (Zimmerman and Minello 1984, Rozas and Reed 1993). Samples were collected in the daytime at high tide using the drop-sampling technique developed by Zimmerman et al. (1984). A temporary tide gauge was installed in the marsh to track changes in water level throughout each sampling period. Six drop samples were collected in each of the four blocks (three in the outer marsh and three in the inner marsh). During the two spring sampling periods, these inner marsh samples were collected approximately 55 m from the open bay shoreline, and the elevational difference between the inner marsh and outer marsh surfaces was approximately 24 cm. During the fall 1988 sampling period, water levels were relatively low, and inner marsh samples were collected at about 35 m into the marsh from the bay; the inner marsh elevation at this location was only 14 cm higher than the outer marsh surface. Within the inner and outer marsh locations, a vegetated sample was taken in the center of the control sector about 35 m away from the experimental channel, a vegetated sample was taken in the experimental sector about 1–2 m from the channel edge, and a nonvegetated sample was taken either within the channel (inner marsh) or just offshore of the marsh (outer marsh) (Figure 3). Thus, in each block, four vegetated drop
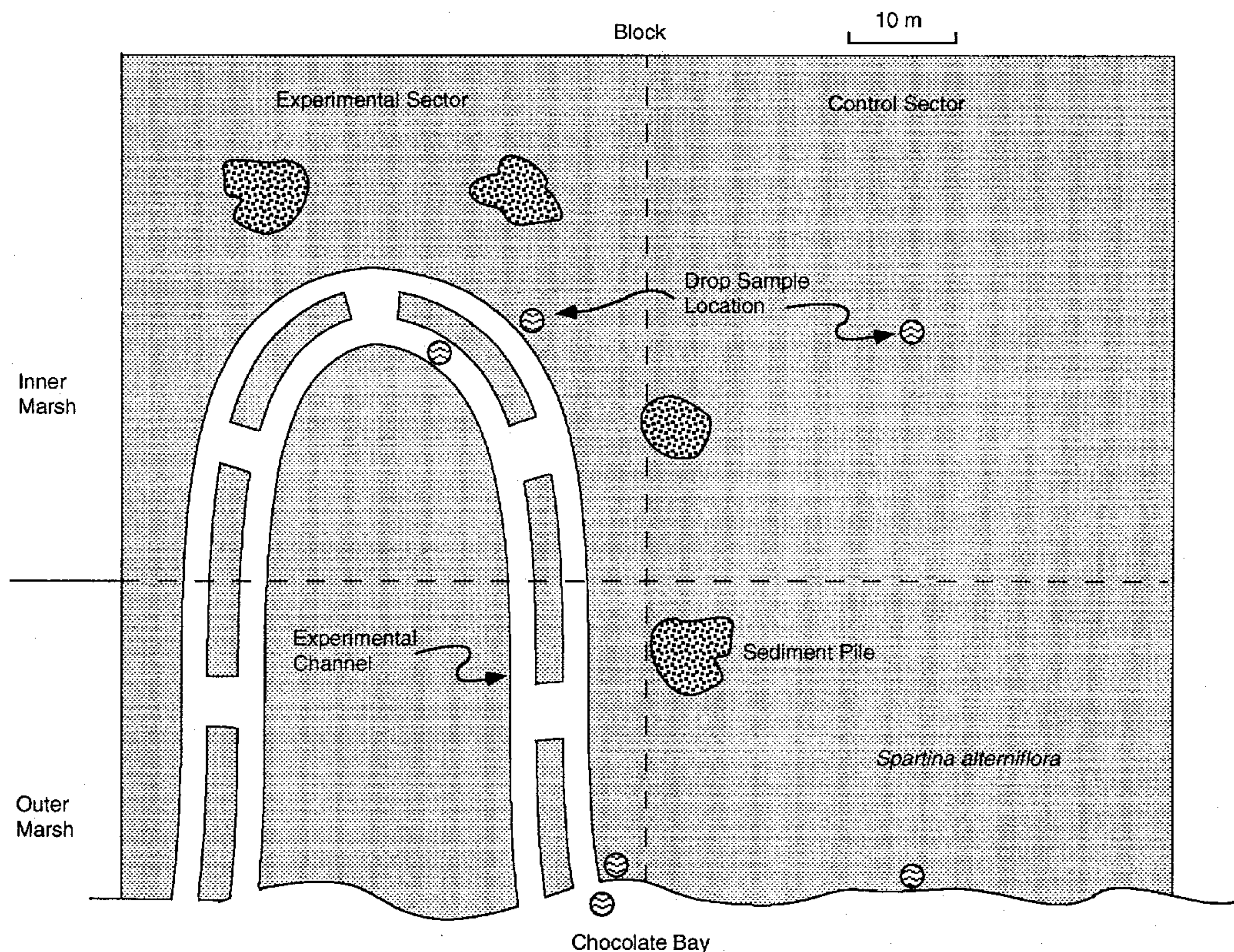
Figure 3. Schematic of one Block in the experimental design showing a constructed channel in the experimental sector. Approximate locations of drop samples are indicated in relation to the channel.

samples were collected on the marsh surface, and three of these samples were edge samples (1–2 m away from either the open bay or the channel); the fourth vegetated sample was about 35 m away from the nearest open water (the inner marsh channel).

The cylindrical drop sampler (1.8 m diameter) was suspended approximately 2 m above the water's surface from a boom mounted on the bow of a boat. Care was taken not to disturb the target area before the sampler was dropped, and the shallow-draft boat was slowly pushed from the stern as each sampling site was approached. The horizontal distances from the center of the sampler to the bow and stern of the boat were 2 m and 7 m, respectively. After the sampler was dropped and pushed into the substratum, water temperature, salinity, and dissolved oxygen were measured within the sampler as described by Minello and Zimmerman (1992). Water samples were also collected,

and turbidity was analyzed in the laboratory with a nephelometer calibrated to a formazin standard (expressed as FTU). Maximum and minimum water depths were measured, and sample water depth was recorded as the midpoint between these values. A 10-cm-diameter (78.5 cm^2) sediment core that included a clump of *S. alterniflora* in the vegetated samples was taken from within each drop sampler (near the center) for the collection of small benthic infauna and epifauna. The upper 5 cm of sediment and the lower 5 cm of the plant stems were washed on a 0.5-mm mesh sieve, and the animals and plant material retained on the sieve were preserved in formalin. The remaining macrophytes within the drop sampler were clipped at the substratum surface and removed to facilitate collection of large macrofauna. Most of the natant macrofauna trapped within the 2.6-m^2 sampler area were captured using dip nets while the water was pumped

out of the enclosure and through a 1-mm mesh net. When the sampler was completely drained, animals remaining on the bottom were picked up by hand. Sampling efficiency using this technique probably varies for different natant fauna, but recovery of enclosed juvenile brown shrimp has been measured at 94% (Zimmerman et al. 1984). Fiddler crabs often escaped into burrows, however, and recovery of this resident species was incomplete. The collections were preserved in formalin with Rose Bengal stain.

In the laboratory, fishes, crustaceans, and molluscs from drop samples (collectively referred to as large macrofauna throughout this paper) were identified to species. Organisms from the sieved sediment cores were separated from detritus and plant stems. These small macrofauna (collectively referred to as infauna in this paper) largely reside in the sediment, although some epifauna were undoubtedly collected from the surfaces of the sediment and plant stems. Amphipods, tanaids, and polychaete worms were identified to species, and remaining organisms were grouped into the lowest feasible taxonomic categories. Animal diversity within the fishes, decapod crustaceans, and infauna was defined as the total number of species or taxa identified from the four samples collected in each habitat type during a sampling period.

Statistical Analyses

The sampling pattern was designed for analysis as a completely randomized block ANOVA with two main effects, Marsh Location and Channel Treatment. Marsh Location had two levels (inner marsh and outer marsh). The Channel Treatment had three levels, including vegetated habitat about 35 m away from a channel (in the control sector), vegetated habitat 1–2 m from a channel (in the experimental sector), and nonvegetated bottom in the experimental sector. In the inner marsh, this nonvegetated bottom was within a channel, while in the outer marsh, nonvegetated bottom was just offshore in shallow open water of Chocolate Bay (Figure 3). A primary comparison of interest was whether the experimental channels had altered the density of animals within the vegetation in the inner marsh (control versus experimental vegetated). This comparison was made through an *a priori* contrast of these cell means (Milliken and Johnson 1984). An additional inner marsh contrast was also made between the control mean and the experimental nonvegetated mean. A probability value of 0.05 was considered significant in all statistical analyses. Heterogeneous variances were assumed for animal densities on the basis of previous data analyses, and a logarithmic (density +1) transformation was used for ANOVAs. Pearson product-moment correlations were also calculated using log-

transformed animal densities. Other variables were not transformed, and untransformed means and standard errors are presented throughout the paper to aid in visualization of patterns. Analyses were conducted using the SuperANOVA software package (Abacus Concepts, Inc., Berkeley, CA, 1989).

RESULTS

Physical and Chemical Variables

Halls Bayou is a source of freshwater runoff located east of the study area, and water salinities at the eastern end of the marsh were generally 2–3 ppt lower than at the western end. This gradient was reflected in significant Block effects in the ANOVAs (all p values < 0.04) for water salinity. Water temperature was generally warmer and dissolved oxygen lower in the inner marsh (Table 1), and the Marsh Location effect was significant at the 0.05 level in several of the ANOVAs for these variables. Overall, the channels had few detectable effects on water temperature, salinity, or dissolved oxygen (Table 1), and the Channel Treatment and interaction terms in the ANOVAs were not significant for these variables (all p values > 0.10). In the fall of 1988, however, there was evidence that the channels did increase dissolved oxygen at the inner marsh sites; means were significantly lower (ANOVA, contrast p values < 0.03) in the control (2.6 ppm) compared with both the experimental vegetated (4.7 ppm) and nonvegetated (4.9 ppm) habitats.

Chocolate Bay is appropriately named and generally quite turbid. Our sample turbidities at the outer marsh sites and in the experimental channels seemed representative of the bay water (Table 1). Mean turbidities were relatively low at the inner marsh control sites, and during the two spring sampling periods, these turbidities were significantly lower than in the channels (ANOVA, contrast p values < 0.01). The high turbidity in the channels during the fall (42.5 FTU) was due to an apparently anomalous observation (136 FTU) at one site. Eliminating this value decreased the mean to 11.3 FTU. Although the sampling crew attempted to reduce their impact on water turbidity, this outlier may indicate some disturbance during sampling.

The effect of channel construction on marsh surface elevation was examined by comparing water depths at the sampling sites. Each sample water depth was standardized for a sampling period based on our tide gauge reading at the time the sample was collected. Standardized water levels in the control and experimental sectors were compared within each of the four blocks over all three sampling periods. In the inner marsh, the mean standardized water depth on the marsh surface was 25.8 cm in the control sector and 28.1 cm

Table 1. Mean values (with standard errors in parentheses, N = 4) for water quality variables measured in six habitat types within the study area. In experimental sectors, samples were collected in both vegetated and nonvegetated habitats.

| | Inner Marsh | | | Outer Marsh | | |
| | Control | Experimental | | Control | Experimental | |
	Spartina	*Spartina*	Channel	*Spartina*	*Spartina*	Open Water
			May 1987			
Salinity (ppt)	29.8 (0.75)	30.3 (0.85)	30.5 (0.87)	29.8 (0.75)	30.3 (0.75)	30.0 (0.58)
Temperature (deg. C)	28.7 (1.17)	28.2 (1.24)	27.7 (1.84)	26.5 (1.86)	27.8 (1.17)	28.5 (0.84)
Dissolved oxygen (ppm)						
Turbidity (FTU)	10.5 (1.55)	29.0 (10.15)	48.5 (7.40)	44.5 (5.95)	47.8 (13.15)	60.5 (14.64)
Depth (cm)	29.0 (0.74)	36.1 (1.39)	71.3 (2.92)	59.8 (6.33)	54.4 (3.13)	58.4 (3.84)
			May 1988			
Salinity (ppt)	24.3 (0.48)	24.0 (0.58)	24.3 (0.48)	23.3 (0.63)	23.5 (0.29)	23.5 (0.87)
Temperature (deg. C)	29.3 (0.39)	29.0 (0.35)	28.6 (0.31)	27.2 (0.50)	27.3 (0.25)	27.0 (0.50)
Dissolved oxygen (ppm)	5.1 (0.37)	4.4 (0.20)	5.3 (0.39)	7.8 (0.18)	7.9 (0.19)	7.6 (0.29)
Turbidity (FTU)	6.8 (1.03)	20.5 (5.58)	38.3 (9.53)	20.0 (5.29)	19.0 (3.37)	35.0 (3.27)
Depth (cm)	32.4 (2.20)	32.9 (0.99)	71.5 (1.61)	41.0 (2.21)	42.5 (3.29)	54.2 (4.34)
			September 1988			
Salinity (ppt)	24.5 (0.65)	24.8 (0.95)	24.0 (0.41)	24.0 (0.41)	23.8 (0.63)	24.0 (0.71)
Temperature (deg. C)	27.3 (0.43)	29.8 (1.00)	29.6 (0.86)	28.6 (0.88)	26.6 (2.21)	28.9 (0.77)
Dissolved oxygen (ppm)	2.6 (0.43)	4.7 (0.73)	4.9 (0.58)	6.4 (1.05)	6.4 (1.33)	6.2 (0.33)
Turbidity (FTU)	9.5 (2.25)	14.8 (4.59)	42.5 (31.25)	15.8 (9.78)	11.8 (1.49)	15.3 (5.31)
Depth (cm)	15.6 (0.55)	12.5 (1.67)	42.1 (1.39)	25.9 (2.38)	31.1 (1.48)	32.8 (3.96)

near the channels in the experimental sector; this difference was not statistically significant (paired-t = −1.76, p = 0.10, 11 pairs). In the outer marsh, the mean standardized water depth was 41.6 cm for the control and 41.8 cm near the channels (paired-t = −0.07, p = 0.95, 12 pairs). Each observation in a pair was made at a similar distance from the open bay, and these comparisons indicate that the construction of the channels did not result in any detectable alteration of the surrounding marsh surface elevation.

Benthic Infauna

Benthic infauna from the sediment cores were dominated by annelid worms, and polychaetes were most abundant within this group (Table 2), making up 51%, 89%, and 77% of all annelids collected during the three sampling periods. Polychaete densities were highest in the outer marsh, and there was a significant effect of Marsh Location in all ANOVAs (p values < 0.005). Lowest polychaete densities occurred at the inner marsh control sites (overall mean density of 2.5 per sediment core), and densities here were significantly lower than at the inner marsh experimental sites (five of six contrasts were significant at the 0.05 level). Three species dominated the polychaetes; *Heteromastus filiformis* was found almost exclusively in outer marsh samples, and *Streblospio benedicti* and *Capitella capitata* were dis-

tributed throughout the marsh (Table 2). Because distributions were patchy, channel effects on the abundance of individual species were difficult to determine. In contrast to the polychaetes, oligochaetes were seldom found on nonvegetated bottom. Within the inner marsh, oligochaete densities were significantly lower in the experimental channels than in the control habitat (ANOVA, all contrast p values < 0.035), but we were unable to detect any significant difference between the experimental and control vegetated habitats (ANOVA, all contrast p values > 0.59). Crustaceans in the sediment cores were mainly amphipods and tanaids. Few crustaceans were present in nonvegetated sediments, and the overall low densities and high spatial variability resulted in few discernible distribution patterns (Table 2) or significant effects in the ANOVAs. The number of infaunal species identified from the sediment cores was highest in vegetated habitats of the outer marsh, and there did not seem to be any channel effects on infaunal diversity.

Large Macrofauna from Drop Samples

The large macrofauna on the vegetated marsh surface were dominated by decapod crustaceans, and the species present were similar during the spring of 1987 and 1988. The most abundant natant decapods were daggerblade grass shrimp *Palaemonetes pugio* and ju-

Table 2. Mean densities (SE) of common benthic infauna from six habitat types within the study area. In experimental sectors, samples were collected in both vegetated and nonvegetated habitats. Each mean (number per 78.5 sq cm) is estimated from four sediment cores. Within major taxa, species are ranked by overall abundance; rare species (no means >0.5) are not listed. The number of species was determined from all four sediment cores (314 sq cm) and includes unlisted rare species.

Species	Inner Marsh			Outer Marsh		
	Control Spartina	Experimental		Control Spartina	Experimental	
		Spartina	Channel		Spartina	Open Water
May 1987						
ANNELIDS	33.5 (21.6)	50.8 (14.7)	13.5 (3.1)	72.8 (31.1)	100.5 (40.2)	20.3 (7.5)
Polychaetes	1.3 (1.3)	24.0 (20.3)	13.3 (3.1)	63.8 (32.9)	26.0 (10.4)	20.3 (7.5)
Heteromastus filiformis (Claparede)	0.0 (0.0)	0.0 (0.0)	1.8 (1.2)	42.8 (26.3)	4.8 (1.0)	7.0 (3.8)
Streblospio benedicti Webster	0.0 (0.0)	20.5 (20.5)	8.8 (2.5)	8.5 (7.2)	3.3 (1.4)	11.5 (5.5)
Capitella capitata (Fabricius)	1.3 (1.3)	3.5 (0.6)	2.8 (1.5)	5.8 (3.5)	15.0 (10.7)	0.8 (0.8)
Nereis (Neanthes) succinea Frey & Leukart	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	5.8 (1.8)	2.3 (0.9)	0.8 (0.8)
Oligochaetes	32.3 (20.4)	26.8 (12.7)	0.3 (0.3)	9.0 (5.6)	74.5 (32.2)	0.0 (0.0)
CRUSTACEANS	2.8 (1.1)	3.5 (0.6)	2.3 (1.3)	5.8 (3.7)	1.3 (0.6)	0.8 (0.5)
Amphipods	2.0 (0.7)	3.3 (0.6)	0.0 (0.0)	4.3 (2.7)	0.5 (0.3)	0.0 (0.0)
Orchestia spp.	2.0 (0.7)	3.3 (0.6)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)
Gammarus mucronatus Say	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.3 (1.4)	0.3 (0.3)	0.0 (0.0)
Corophium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.5 (0.5)	0.0 (0.0)	0.0 (0.0)
Tanaids						
Hargeria rapax (Harger)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)
MOLLUSCS	0.8 (0.5)	1.3 (0.5)	0.5 (0.3)	0.3 (0.3)	0.3 (0.3)	0.0 (0.0)
Number of Species	8	7	7	22	15	7
May 1988						
ANNELIDS	16.8 (7.8)	19.5 (4.7)	23.8 (6.1)	85.0 (48.2)	81.8 (21.7)	45.5 (18.3)
Polychaetes	4.5 (2.1)	13.8 (3.4)	23.8 (6.1)	75.3 (45.3)	80.3 (21.9)	43.8 (17.2)
Heteromastus filiformis (Claparede)	0.5 (0.5)	0.3 (0.3)	7.5 (4.7)	18.8 (11.8)	38.0 (13.4)	19.8 (10.4)
Streblospio benedicti Webster	1.5 (1.5)	0.0 (0.0)	9.8 (3.8)	35.3 (34.9)	11.5 (8.2)	14.5 (9.2)
Capitella capitata (Fabricius)	2.5 (1.0)	13.0 (3.1)	6.3 (2.5)	17.8 (8.2)	22.5 (14.0)	3.5 (0.5)
Nereis (Neanthes) succinea Frey & Leukart	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	2.0 (1.4)	3.3 (2.0)	0.8 (0.5)
Oligochaetes	12.3 (7.6)	5.8 (4.3)	0.0 (0.0)	9.8 (4.8)	1.5 (0.3)	1.8 (1.0)
CRUSTACEANS	2.3 (0.6)	0.8 (0.5)	0.0 (0.0)	1.3 (0.9)	4.3 (3.0)	0.0 (0.0)
Amphipods	1.8 (0.5)	0.3 (0.3)	0.0 (0.0)	1.3 (0.9)	1.5 (0.6)	0.0 (0.0)
Gammarus mucronatus Say	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.5 (0.3)	1.5 (0.6)	0.0 (0.0)
Orchestia spp.	1.3 (0.5)	0.3 (0.3)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)
Tanaids						
Hargeria rapax (Harger)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	2.8 (2.8)	0.0 (0.0)
MOLLUSCS	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.8 (0.5)	0.5 (0.5)	0.0 (0.0)
Number of Species	10	11	7	15	15	8
September 1988						
ANNELIDS	20.5 (11.1)	20.3 (4.8)	10.0 (3.0)	30.8 (13.4)	51.8 (20.6)	12.5 (3.9)
Polychaetes	1.8 (1.0)	10.5 (3.4)	10.0 (3.0)	27.8 (13.2)	49.3 (19.0)	12.3 (3.8)
Streblospio benedicti Webster	0.3 (0.3)	1.5 (0.9)	8.5 (2.1)	17.5 (8.2)	35.0 (12.7)	6.0 (2.3)
Capitella capitata (Fabricius)	1.5 (1.0)	9.0 (3.5)	0.0 (0.0)	3.0 (1.2)	2.5 (1.8)	0.3 (0.3)
Heteromastus filiformis (Claparede)	0.0 (0.0)	0.0 (0.0)	0.8 (0.5)	5.3 (4.6)	6.8 (4.5)	2.0 (0.9)
Nereis (Neanthes) succinea Frey & Leukart	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.3 (0.6)	1.3 (0.5)	0.0 (0.0)
Oligochaetes	18.8 (10.4)	9.8 (2.4)	0.0 (0.0)	3.0 (1.2)	2.5 (1.6)	0.3 (0.3)
CRUSTACEANS	2.5 (1.0)	6.8 (3.5)	8.3 (4.3)	7.0 (3.4)	11.3 (4.9)	0.8 (0.5)
Amphipods	1.5 (0.9)	1.0 (0.4)	0.0 (0.0)	5.5 (3.2)	6.3 (1.9)	0.3 (0.3)
Gammarus mucronatus Say	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	4.8 (3.4)	3.8 (1.1)	0.3 (0.3)

Table 2. Continued.

Species	Inner Marsh			Outer Marsh		
	Control *Spartina*	Experimental		Control *Spartina*	Experimental	
		Spartina	Channel		*Spartina*	Open Water
Grandidierella bonnieroides Stephenson	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.8 (0.5)	1.5 (1.0)	0.0 (0.0)
Orchestia spp.	1.3 (0.9)	0.8 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Corophium spp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (0.7)	0.0 (0.0)
Tanaids						
Hargeria rapax (Harger)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	1.0 (1.0)	0.0 (0.0)
MOLLUSCS	0.0 (0.0)	1.0 (0.4)	0.0 (0.0)	0.0 (0.0)	0.5 (0.3)	0.0 (0.0)
Number of species	9	12	7	13	18	8

venile brown shrimp *Penaeus aztecus* (Table 3). The gulf marsh fiddler crab *Uca longisignalis* was also common in the spring samples. During the fall sampling period, the above three species were present, but white shrimp *Penaeus setiferus* and blue crabs *Callinectes sapidus* were abundant as well. Overall, decapod distributions within the inner marsh showed greater use of the marsh surface near the channels compared with the control habitat (the effect was significant in the spring of 1987 and the fall of 1988, Table 4). These decapod densities, however, included the resident gulf marsh fiddler crab population, and densities of *U. longisignalis* on the inner marsh surface were not significantly affected by the experimental channels. In contrast, distributions of caridean and penaeid shrimp were dramatically affected by the channels. Daggerblade grass shrimp and brown shrimp were present in only low numbers at the inner marsh control sites (Table 3), and the channels significantly increased densities on the inner marsh surface during all three sampling periods (Table 4). White shrimp densities at vegetated sites showed a similar pattern in the fall samples; densities in the inner marsh were significantly higher near the channels (ANOVA contrast p = 0.001). Densities of white shrimp on nonvegetated bottom, however, were also relatively high. In contrast to shrimp distributions, fall blue crab densities in the inner marsh did not seem to be affected by the channels (ANOVA, contrast p values > 0.33), and blue crabs were abundant in all habitats except on nonvegetated bottom in the outer marsh (Table 3).

The fishes collected during both spring sampling periods were dominated by small schooling bait species such as the bay anchovy *Anchoa mitchilli* and the inland silverside *Menidia beryllina* (Table 3). Fishes were most abundant in the experimental channels of the inner marsh, and the mean density of bay anchovies in this habitat was over 53 per m² in the spring of 1987. Fishes were less abundant in the fall samples,

with blackcheek tonguefish *Symphurus plagiusa* and young spotted seatrout *Cynoscion nebulosus* predominating. In the statistical analyses of fish density patterns, there were significant interactions in all three sampling periods between Marsh Location and the Channel Treatment (Table 4). These interactions are attributable to high densities in the channels. The effect of the channels on fish density was also indicated by the highly significant contrasts in the inner marsh between densities in the control and channel habitats (Table 4). Within vegetation in the inner marsh, mean fish densities were always higher near the channels compared with the control sector, but the contrast of this difference was only significant at the 0.05 level during the spring of 1987 when no fishes were collected in the control samples.

DISCUSSION

Marsh-edge habitat is used by high densities of transient and resident nekton in the coastal salt marshes of the northern Gulf of Mexico (Zimmerman and Minello 1984, Thomas et al. 1990, Baltz et al. 1993, Rozas 1993, Rozas and Reed 1993, Peterson and Turner 1994). The large amount of edge in these marshes, compared with other coastal marshes, has been proposed as one reason for the high productivity of estuarine-dependent fisheries in the northern Gulf (Faller 1979, Gosselink 1984, Zimmerman et al. 1984, Browder et al. 1985, 1989). Elevation of the marsh surface and flooding duration have also been proposed as important factors controlling marsh use and value (Zimmerman and Minello 1984, Hummel et al. 1986, Childers et al. 1990, Morris et al. 1990, Minello and Zimmerman 1991, Zimmerman et al. 1991, Rozas and Reed 1993). Animal densities in a natural marsh with some variability in shoreline slope suggest that both elevation and distance to the marsh edge are important in determining marsh use by brown shrimp (Figure 4)

Table 3. Mean densities (SE) of common large macrofauna from six habitat types within the study area. In experimental sectors, samples were collected in both vegetated and nonvegetated habitats. Each mean (number per 2.6 sq m) is estimated from four drop samples. Within major taxa, species are ranked by overall abundance; rare species (no means > 1.0) are not listed. The number of species was determined from all four drop samples (10.4 sq m) and includes unlisted rare species.

| | Inner Marsh | | | Outer Marsh | | |
| | Control | Experimental | | Control | Experimental | |
Species	*Spartina*	*Spartina*	Channel	*Spartina*	*Spartina*	Open Water
May 1987						
FISHES	0.0 (0.0)	6.0 (3.4)	199.5 (26.4)	24.0 (12.3)	22.5 (7.4)	26.5 (9.2)
Anchoa mitchilli (Valenciennes)	0.0 (0.0)	0.5 (0.5)	160.3 (27.9)	12.8 (12.1)	0.5 (0.5)	19.0 (10.9)
Menidia beryllina (Cope)	0.0 (0.0)	1.5 (1.2)	7.3 (2.3)	5.8 (3.8)	12.8 (4.4)	6.3 (5.0)
Gobiosoma bosc (Lacepede)	0.0 (0.0)	0.0 (0.0)	22.8 (17.5)	1.0 (1.0)	2.5 (2.5)	0.0 (0.0)
Brevoortia patronus Goode	0.0 (0.0)	2.5 (2.5)	6.8 (5.8)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Mugil cephalus Linnaeus	0.0 (0.0)	0.8 (0.8)	0.5 (0.5)	0.8 (0.3)	1.8 (0.9)	0.0 (0.0)
Myrophis punctatus Lutken	0.0 (0.0)	0.3 (0.3)	0.5 (0.5)	1.0 (0.7)	1.3 (0.9)	0.3 (0.3)
Lagodon rhomboides (Linnaeus)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	1.0 (0.7)	0.8 (0.5)	0.0 (0.0)
Leiostomus xanthurus Lacepede	0.0 (0.0)	0.0 (0.0)	0.5 (0.3)	0.0 (0.0)	0.3 (0.3)	1.0 (0.7)
Bairdiella chrysura (Lacepede)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	1.3 (0.9)	0.0 (0.0)
Number of species	0	7	11	11	13	4
DECAPOD CRUSTACEANS	44.5 (8.6)	82.3 (5.3)	12.3 (1.5)	87.0 (7.4)	102.5 (19.5)	10.5 (3.5)
Palaemonetes pugio Holthuis	7.8 (2.5)	21.5 (2.8)	1.0 (0.7)	45.3 (6.2)	72.8 (19.7)	0.0 (0.0)
Uca longisignalis Salmon & Atsaides	34.5 (6.7)	51.0 (3.8)	0.8 (0.5)	2.5 (2.2)	0.0 (0.0)	0.0 (0.0)
Penaeus aztecus Ives	2.0 (0.4)	7.5 (1.7)	9.5 (1.3)	32.0 (3.3)	24.3 (1.2)	10.3 (3.3)
Callinectes sapidus Rathbun	0.0 (0.0)	1.5 (0.3)	0.3 (0.3)	4.0 (1.9)	3.8 (0.5)	0.3 (0.3)
Clibanarius vittatus (Bosc)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.5 (1.0)	1.8 (0.3)	0.0 (0.0)
Number of species	4	5	6	7	4	2
MOLLUSCA	0.3 (0.3)	4.3 (2.7)	4.5 (3.5)	9.0 (3.1)	17.0 (13.5)	1.0 (0.7)
Littorina irrorata (Say)	0.0 (0.0)	4.0 (2.7)	0.0 (0.0)	8.3 (3.4)	16.0 (13.7)	0.0 (0.0)
May 1988						
FISHES	0.8 (0.3)	14.8 (8.0)	70.3 (42.1)	22.8 (7.6)	16.0 (5.7)	5.3 (2.2)
Anchoa mitchilli (Valenciennes)	0.0 (0.0)	0.0 (0.0)	57.8 (40.5)	0.0 (0.0)	0.0 (0.0)	1.5 (1.5)
Menidia beryllina (Cope)	0.3 (0.3)	7.0 (7.0)	4.3 (3.6)	12.8 (6.5)	8.0 (3.0)	0.0 (0.0)
Mugil cephalus Linnaeus	0.0 (0.0)	6.8 (3.6)	1.0 (1.0)	3.0 (1.7)	1.3 (0.6)	0.5 (0.3)
Bairdiella chrysura (Lacepede)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.3 (5.9)	5.0 (3.1)	0.0 (0.0)
Cyprinodon variegatus Lacepede	0.0 (0.0)	0.0 (0.0)	6.8 (6.8)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Lagodon rhomboides (Linnaeus)	0.0 (0.0)	0.8 (0.5)	0.0 (0.0)	0.5 (0.3)	1.3 (0.3)	0.3 (0.3)
Brevoortia patronus Goode	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.5 (2.5)
Number of species	3	4	5	5	6	5
DECAPOD CRUSTACEANS	54.5 (10.0)	58.5 (9.5)	6.5 (1.6)	74.5 (19.7)	121.5 (29.5)	3.0 (1.3)
Palaemonetes pugio Holthuis	8.3 (3.7)	18.5 (1.6)	0.5 (0.3)	61.0 (18.1)	97.5 (28.4)	1.0 (0.7)
Uca longisignalis Salmon & Atsaides	44.5 (9.0)	33.8 (7.5)	0.0 (0.0)	3.8 (1.9)	2.3 (2.3)	0.3 (0.3)
Penaeus aztecus Ives	1.5 (0.5)	4.8 (0.9)	5.8 (1.4)	5.8 (1.0)	17.0 (4.5)	1.8 (0.9)
Sesarma cinereum (Bosc)	0.0 (0.0)	1.5 (1.2)	0.0 (0.0)	1.8 (1.2)	0.8 (0.8)	0.0 (0.0)
Callinectes sapidus Rathbun	0.3 (0.3)	0.0 (0.0)	0.3 (0.3)	0.8 (0.5)	2.3 (0.5)	0.0 (0.0)
Clibanarius vittatus (Bosc)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (0.4)	1.8 (1.0)	0.0 (0.0)
Number of species	4	4	3	8	6	3
MOLLUSCA	8.0 (3.9)	24.8 (6.5)	25.0 (22.7)	52.8 (16.0)	50.5 (12.1)	3.0 (2.3)
Littorina irrorata (Say)	6.0 (3.9)	24.7 (6.5)	0.0 (0.0)	52.5 (15.9)	50.5 (12.1)	0.5 (0.3)
September 1988						
FISHES	1.5 (0.6)	3.5 (2.2)	23.8 (7.4)	10.0 (3.8)	8.5 (3.5)	8.0 (2.1)
Symphurus plagiusa (Linnaeus)	0.0 (0.0)	1.0 (0.7)	4.5 (1.8)	2.3 (0.9)	3.5 (1.3)	3.0 (0.7)
Cynoscion nebulosus (Cuvier)	0.0 (0.0)	0.3 (0.3)	5.8 (2.1)	3.5 (1.3)	0.5 (0.3)	2.8 (1.2)

Table 3. Continued.

Species	Inner Marsh			Outer Marsh		
	Control *Spartina*	Experimental		Control *Spartina*	Experimental	
		Spartina	Channel		*Spartina*	Open Water
Mugil cephalus Linnaeus	0.0 (0.0)	0.8 (0.8)	5.5 (3.3)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)
Gobiosoma bosc (Lacepede)	0.0 (0.0)	0.5 (0.5)	2.3 (0.8)	0.5 (0.5)	2.8 (1.5)	0.3 (0.3)
Gobionellus boleosoma (Jordan & Gilbert)	0.0 (0.0)	1.0 (0.4)	1.3 (0.5)	1.3 (0.9)	0.8 (0.8)	1.0 (0.4)
Menidia beryllina (Cope)	0.0 (0.0)	0.0 (0.0)	2.0 (1.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Number of species	4	5	12	10	7	6
DECAPOD CRUSTACEANS	94.3 (17.9)	334.0 (107.8)	107.3 (50.3)	295.5 (76.8)	287.5 (37.2)	58.8 (26.1)
Palaemonetes pugio Holthuis	4.0 (1.8)	101.8 (57.7)	42.5 (41.2)	139.8 (34.1)	144.3 (36.7)	0.0 (0.0)
Penaeus setiferus (Linnaeus)	7.5 (3.4)	102.3 (64.0)	21.0 (4.7)	30.3 (23.9)	51.0 (9.8)	46.5 (24.3)
Callinectes sapidus Rathbun	24.3 (5.1)	29.8 (5.4)	34.3 (5.4)	47.0 (14.1)	32.5 (8.9)	10.0 (2.3)
Penaeus aztecus Ives	7.8 (2.5)	41.5 (17.3)	8.5 (5.3)	60.5 (26.5)	35.3 (10.1)	1.0 (0.4)
Uca longisignalis Salmon & Atsaides	49.3 (12.9)	33.0 (20.3)	0.5 (0.5)	0.5 (0.3)	22.3 (21.6)	1.0 (0.7)
Sesarma reticulatum (Say)	1.3 (0.8)	3.5 (1.9)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)
Clibanarius vittatus (Bosc)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	2.3 (0.9)	0.8 (0.5)	0.0 (0.0)
Sesarma cinereum (Bosc)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	1.8 (0.8)	0.5 (0.5)	0.0 (0.0)
Number of species	7	9	6	10	11	4
MOLLUSCA	19.3 (10.9)	21.0 (9.4)	0.0 (0.0)	57.0 (21.0)	11.0 (2.9)	1.0 (1.0)
Littorina irrorata (Say)	19.0 (10.8)	20.5 (9.5)	0.0 (0.0)	56.5 (20.9)	11.0 (2.9)	0.0 (0.0)

and other nekton (Minello et al. 1991). In this experimental study, we essentially removed the effect of elevation by constructing channels in a created salt marsh, and we directly tested whether proximity to the edge was important in determining use of the marsh surface.

Natant decapods including brown shrimp, white shrimp, and daggerblade grass shrimp showed a strong affinity for marsh-edge habitat, and the experimental channels increased densities of these species on the inner marsh surface by a factor ranging from 4.6 to 13 (Figure 5). The channel habitat itself was also used by these decapods more than inner marsh control habitats. Peterson and Turner (1994) identified brown shrimp and white shrimp as edge species in a natural marsh, and densities of *Palaemonetes* were also highest within 3 m of a marsh creek. However, the confounding of proximity to the creek and marsh elevation in their study along with the presence of a creekside berm, made it difficult to distinguish between the effects of elevation and edge. In our experiment, there was no creekside berm or detectable elevational difference between inner marsh edge habitat and inner marsh control habitat (35 m away from the channels).

The distribution of natant decapods within flooded marsh vegetation may be related to various salt marsh functions. Vegetative structure provides some decapods protection from fish predators (Minello and Zimmerman 1983, Minello et al. 1989, Thomas 1989), but it seems unlikely that vegetation along channels would confer more protection than vegetation away from

channels. Natant decapods also forage on the marsh surface, and distributions of these predators may have been related to the increased densities of polychaete prey along channels (Table 2). Densities of shrimps (daggerblade grass shrimp and penaeids) in drop samples from the marsh surface were positively correlated with densities of polychaetes in associated sediment cores during each of the three sampling periods (r= 0.60–0.73, p < 0.015, n= 16). The abundance of infaunal organisms in marsh sediments has been related to many factors, including predation by natant macrofauna (Van Dolah 1978, Kneib 1982, 1984, 1985, Zimmerman et al. 1991, Minello and Zimmerman 1992), but increased sediment drainage near channels (Yelverton and Hackney 1986, Harvey et al. 1987, Whiting and Childers 1989) may have benefited polychaete populations. Although channels had minimal effects on surface water quality (Table 1), sediment pore water salinity was significantly reduced near the channels (unpublished data). Kneib (1984) also reported highest marsh densities of the polychaete *Streblospio benedicti* near a natural creek. In both natural and created marshes in North Carolina, Moy and Levin (1991) observed a general trend of decreasing densities of *S. benedicti* with distance from open water (measured as elevation), but distribution patterns were inconsistent and seemed to vary both temporally and among marshes.

Overlying the pursuit of food and protective cover in a marsh, may be a requirement for departure from

Table 4. ANOVA results testing for effects of the Channel Treatment (control, experimental-vegetated, experimental-non-vegetated) and Marsh Location (inner, outer) on density of large macrofauna from drop samples. Contrasts compare cell means of the inner marsh. All animal densities were transformed, $\log(x + 1)$.

Source	df	Spring 87		Spring 88		Fall 88	
		SS	P	SS	P	SS	P
Fishes							
Total	23	71.85		44.22		22.96	
Channel Trt	2	32.38	0.000	3.04	0.335	6.39	0.020
Marsh Loc	1	2.58	0.048	0.93	0.410	0.79	0.278
Channel Trt*Loc	2	26.34	0.000	18.37	0.006	5.72	0.028
Block	3	2.16	0.314	2.45	0.606	0.69	0.779
Error	15	8.39		19.43		9.38	
Contrasts (Inner Marsh)							
Control vs Trt (Veg)	1	5.15	0.008	4.91	0.070	0.36	0.457
Control vs Trt (NVeg)	1	55.64	0.000	17.49	0.002	10.65	0.000
Decapods							
Total	23	24.47		46.34		21.35	
Channel Trt	2	19.95	0.000	38.62	0.000	10.29	0.000
Marsh Loc	1	0.19	0.318	0.01	0.849	0.08	0.619
Channel Trt*Loc	2	1.06	0.085	2.24	0.059	3.26	0.016
Block	3	0.53	0.435	0.53	0.660	3.22	0.039
Error	15	2.73		4.92		4.50	
Contrasts (Inner Marsh)							
Control vs Trt (Veg)	1	0.86	0.046	0.01	0.834	2.79	0.008
Control vs Trt (NVeg)	1	2.87	0.001	8.13	0.000	0.01	0.841
Palaemonetes pugio							
Daggerblade grass shrimp							
Total	23	64.11		65.73		104.16	
Channel Trt	2	50.36	0.000	47.51	0.000	51.30	0.000
Marsh Loc	1	3.71	0.002	8.67	0.000	3.25	0.130
Channel Trt*Loc	2	5.64	0.001	3.33	0.017	28.47	0.001
Block	3	0.25	0.826	1.59	0.205	2.08	0.658
Error	15	4.15		4.62		19.06	
Contrasts (Inner Marsh)							
Control vs Trt (Veg)	1	2.36	0.010	1.78	0.029	14.97	0.003
Control vs Trt (NVeg)	1	4.41	0.001	5.59	0.000	0.45	0.560
Penaeus aztecus Brown shrimp							
Total	23	18.35		15.28		45.29	
Channel Trt	2	0.73	0.192	4.21	0.005	22.96	0.000
Marsh Loc	1	8.04	0.000	0.79	0.110	0.43	0.437
Channel Trt*Loc	2	6.32	0.000	5.52	0.001	8.67	0.009
Block	3	0.29	0.690	0.66	0.513	3.09	0.249
Error	15	2.96		4.11		10.14	
Contrasts (Inner Marsh)							
Control vs Trt (Veg)	1	1.98	0.006	1.59	0.029	3.83	0.031
Control vs Trt (NVeg)	1	3.15	0.001	2.08	0.014	0.22	0.579
Uca longisignalis							
Gulf marsh fiddler crab							
Total	23	69.65		63.89		77.91	
Channel Trt	2	17.93	0.000	26.65	0.000	20.11	0.033
Marsh Loc	1	34.16	0.000	17.82	0.000	10.80	0.048
Channel Trt*Loc	2	12.65	0.000	11.00	0.001	8.92	0.182
Block	3	0.14	0.933	0.66	0.738	3.06	0.729
Error	15	4.78		7.76		35.02	
Contrasts (Inner Marsh)							
Control vs Trt (Veg)	1	0.37	0.300	0.15	0.595	1.57	0.424
Control vs Trt (NVeg)	1	18.82	0.000	28.16	0.000	25.31	0.004

the marsh surface at low tide, and high nekton densities near channels in a flooded marsh may simply reflect this requirement. Kneib (1987) showed that small pools of water on the marsh surface could provide low-tide refuge for some larval and small postlarval organisms, but larger nekton must retreat to subtidal habitats. Therefore, nekton that penetrate the marsh far from channels and creeks may be more susceptible to stranding as the tide falls. Water in the created channels provided a refuge from stranding in the inner marsh because channels never drained completely at low tide. The potential for low-tide stranding is probably affected by tidal dynamics and marsh slope.

Densities of abundant small bait fishes, such as the bay anchovy and inland silverside, also increased on the inner marsh surface near channels, but most of these fishes were collected within the channels themselves (Figure 5). Common resident marsh fishes such as killifishes (Cyprinodontidae) were rare in our samples. Low numbers of killifishes have been collected previously in this marsh (Minello and Zimmerman 1992), and these fishes may follow the rising tide further into the marsh and remain in very shallow water (Rozas and Reed 1993, Peterson and Turner 1994).

The abundance and distribution of the two dominant crab species within the marsh were unaffected by the channels. Juvenile blue crabs were distributed evenly among all inner marsh habitats. Lin (1989) suggested that blue crabs traveled 30–35 m into interior salt marshes of Georgia to prey on mussels, and Peterson and Turner (1994) collected blue crabs 20–40 m away from a marsh creek. In comparison to shrimp and fish, blue crabs probably have superior capabilities when exiting a marsh on receding tides. This species can tolerate considerable desiccation and can walk over dry marsh surfaces for short distances. Similarly, densities of the terrestrial gulf marsh fiddler crab on the marsh surface were unaffected by the channels. Overall densities in the inner marsh decreased, however, because the channels themselves were not inhabited by these crabs.

This field experiment was not designed to examine the effect of elevation on use of the marsh surface, but a comparison of animal densities in edge habitat along the bay (outer marsh, vegetated habitats) and edge habitat of the inner marsh (inner marsh, experimental vegetated) should offer some insight into an elevation effect. This comparison requires an assumption that distance from the edge of a channel or creek is equivalent to distance from an open bay. There was some evidence for an elevation effect on the distribution of daggerblade grass shrimp and brown shrimp during the spring sampling periods; the elevation of the inner marsh surface sampled in the spring was about 24 cm higher than the outer marsh surface. Densities of dag-
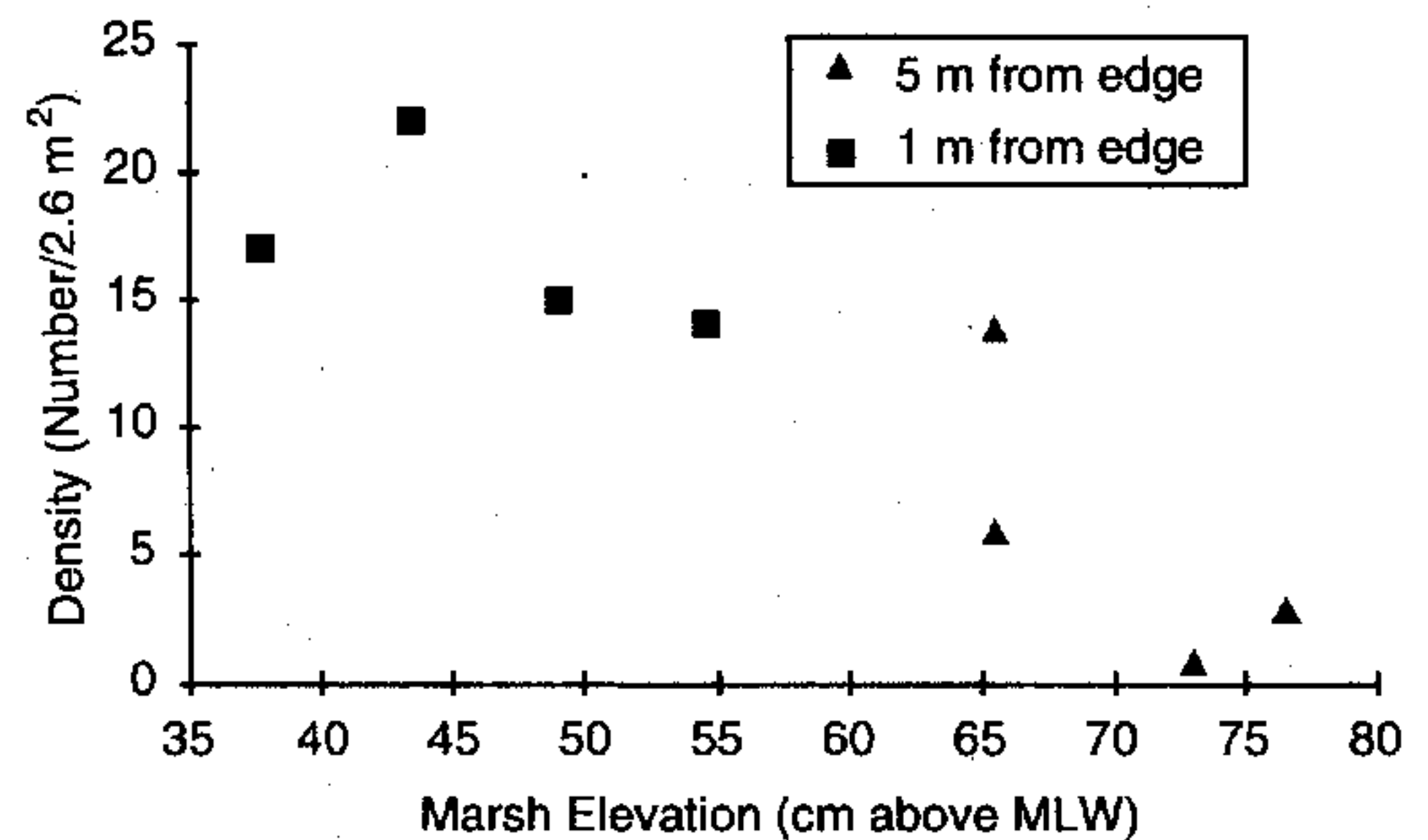

Figure 4. The relationship between marsh elevation and density of juvenile brown shrimp in a natural *Spartina alterniflora* marsh along the shoreline of Halls Lake (Figure 1) in West Galveston Bay (taken from Minello et al. 1991).

gerblade grass shrimp were 2.7 and 4.3 times higher on the low-elevation marsh surface during these sampling periods (ANOVA, contrast p values < 0.014). Mean densities of brown shrimp were also significantly higher on low-elevation marsh surface during the spring of 1987 (3.8 times higher, contrast p = 0.002), but in the spring of 1988, the difference (2.4 times higher) was not statistically significant (contrast p = 0.08). In the fall, the inner marsh sampled was only 14 cm higher in elevation than the outer marsh surface; no effect of this elevational difference was detectable on densities of daggerblade grass shrimp, brown shrimp, or white shrimp during this sampling period (ANOVA, all contrast p values > 0.13).

Both marsh surface elevation and edge should be considered when designing salt marsh habitats. The creation of low-elevation marshes to maximize flooding duration will probably benefit many species of fishes and crustaceans that use marsh surfaces (Zimmerman and Minello 1984, Minello and Zimmerman 1991, Zimmerman et al. 1991, Rozas and Reed 1993). However, survival of emergent marsh plants is also controlled by flooding duration (Mendelssohn and Seneca 1980, McKee and Patrick 1988, Mendelssohn and McKee 1988), and low-elevation marshes are susceptible to drowning due to marsh compaction, subsidence, and rising sea level. The addition of edge habitat alone (without a change in marsh elevation) can also improve the value of a created salt marsh as measured by an increased use of the marsh surface on flood tide. Creation of tidal creeks with shallow shoreline slopes will add both edge and low elevation habitat and should improve the value of a created salt marsh substantially.

Optimal creek density in a salt marsh probably depends upon the animal species of interest and the extent of the edge effect away from the creek. If there are three distinct habitats (creek, marsh edge, and inner

8% 1%

Fishes   91%

(N=1280)

10%

21%

69%

Palaemonetes pugio

(N=823)

13%

27%

60%

Penaeus aztecus

(N=355)

48%   51%

1%

Uca longisignalis (N=989)

6%

16%

78%

Penaeus setiferus

(N=524)

27%

35%

Marsh edge   Control
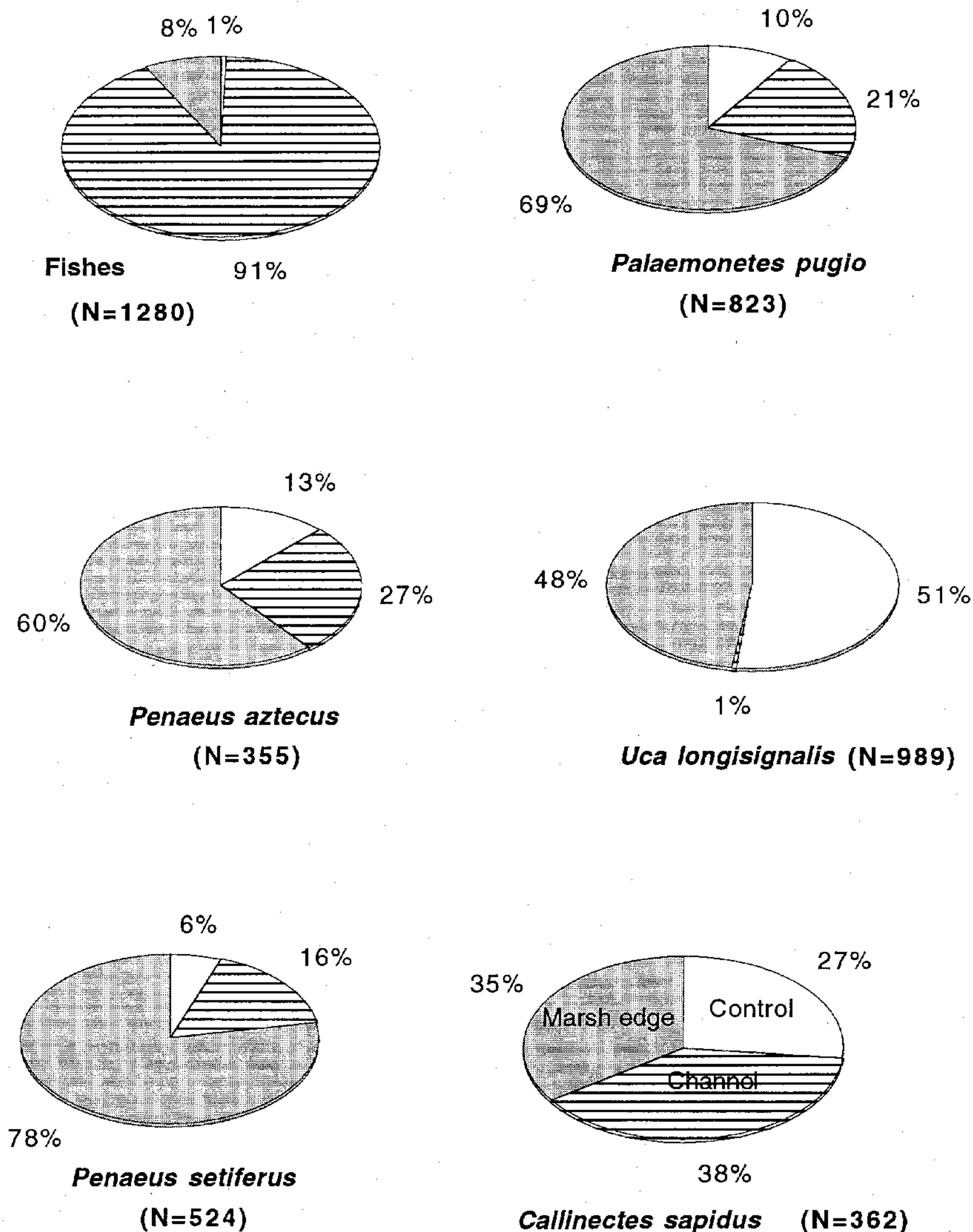
Channel

38%

Callinectes sapidus   (N=362)

Figure 5.   The relative use of three inner marsh habitats by dominant large macrofauna. The percentage for each habitat is based on densities collected with the drop sampling technique during all three sampling periods. Control represents vegetated (*Spartina alterniflora*) habitat without edge ☐, marsh edge represents vegetated habitat along created marsh channels or creeks ▦, and channel represents habitat within the creeks ▤. N is the total number of animals collected in the inner marsh samples.

marsh without edge), our data indicate that completely replacing inner marsh habitat with creeks and marsh edge habitat would increase use of the marsh surface for most nekton. Table 5 presents hypothetical changes in habitat use when inner marsh habitat without edge is replaced with creek and edge habitat at different ratios. These ratios could be constructed by adjusting creek density and size if the extent of the edge effect away from the creek was known. The edge effect in natural salt marshes probably extends several meters

Table 5. Hypothetical increases (or decreases if below 1) in created marsh use if inner marsh habitat without edge is converted entirely to creek and edge habitat at various ratios. These multipliers are based on inner marsh densities presented in Table 3 and marsh use patterns shown in Figure 5. As an example, the table indicates that overall abundance of white shrimp in a flooded marsh would increase by a factor of 10.9 if solid inner marsh was replaced with 25% creek habitat and 75% marsh-edge habitat.

	Creek : edge habitat ratio		
	10:90	25:75	50:50
Fishes	22.7	40.7	70.6
Crustaceans	2.3	2.0	1.6
Daggerblade grass shrimp	6.6	5.9	4.6
Gulf marsh fiddler crab	0.8	0.7	0.5
Brown shrimp	4.5	4.1	3.4
Blue crab	1.3	1.3	1.3
White shrimp	12.6	10.9	8.2

in from the marsh/water interface along creeks and ponds. In a Louisiana salt marsh, Peterson and Turner (1994) showed that most shrimp, crabs, and fishes using the marsh surface were found within 3 m of a marsh creek. In a limited data set from a natural marsh near Chocolate Bay, Minello et al. (1991) found that brown shrimp densities on the marsh surface decreased with distance from open water within the first 5 m of vegetation. This distance effect, however, was apparently diminished when elevations of the marsh surface were similar (Figure 4). Thus, the lateral extent of the edge effect depends upon marsh slope and elevation, and the effect may also be related to tidal dynamics, vegetation type and density, and sediment type and drainage characteristics.

Construction of channels and habitat edge can be an engineering challenge in salt marshes created on dredged material. Once the deposited sediment becomes sufficiently consolidated, various types of earth-moving equipment can be used to create channels and ponds. If the marsh is already established, channels can be created with a dragline or backhoe, but this procedure is expensive and could be destructive to the marsh in general. We have also tried a rotary ditcher that sprays sediment over the marsh surface, and this technique can be used to create channels either before or after the vegetation is established. The best time to create topographic variability in a marsh surface, however, is probably at the time of sediment deposition. With sandy or easily consolidated sediments, proper management of the outflow pipe during hydraulic dredging can create sediment mounds that should result in extensive edge within the marsh. The fluid nature of fine-grained sediments, however, may require some innovative techniques to displace sediment from eventual channels and ponds until the remaining sediment consolidates.

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